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EDITORIAL

Special issue on time scale algorithms

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This special issue of *Metrologia* presents selected papers from the Fifth International Time Scale Algorithm Symposium (VITSAS), including some of the tutorials presented on the first day. The symposium was attended by 76 persons, from every continent except Antarctica, by students as well as senior scientists, and hosted by the Real Instituto y Observatorio de la Armada (ROA) in San Fernando, Spain, whose staff further enhanced their nation's high reputation for hospitality.

Although a timescale can be simply defined as a weighted average of clocks, whose purpose is to measure time better than any individual clock, timescale theory has long been and continues to be a vibrant field of research that has both followed and helped to create advances in the art of timekeeping. There is no perfect timescale algorithm, because every one embodies a compromise involving user needs. Some users wish to generate a constant frequency, perhaps not necessarily one that is well-defined with respect to the definition of a second. Other users might want a clock which is as close to UTC or a particular reference clock as possible, or perhaps wish to minimize the maximum variation from that standard. In contrast to the *steered* timescales that would be required by those users, other users may need *free-running* timescales, which are independent of external information. While no algorithm can meet all these needs, every algorithm can benefit from some form of tuning. The optimal tuning, and even the optimal algorithm, can depend on the noise characteristics of the frequency standards, or of their comparison systems, the most precise and accurate of which are currently Two Way Satellite Time and Frequency Transfer (TWSTFT) and GPS carrier phase time transfer.

The interest in time scale algorithms and its associated statistical methodology began around 40 years ago when the Allan variance appeared and when the metrological institutions started realizing ensemble atomic time using more than one single atomic clock. An international symposium dedicated to these topics was initiated in 1972 as the first *International Symposium on Atomic Time Scale Algorithms* and it was the beginning of a series:

- 1st Symposium: organized at the NIST (NBS at that epoch) in 1972,
- 2nd Symposium: again at the NIST in 1982,
- 3rd Symposium: in Italy at the INRIM (IEN at that epoch) in 1988,
- 4th Symposium: in Paris at the BIPM in 2002 (see *Metrologia* **40** (3), 2003)
- 5th Symposium: in San Fernando, Spain at the ROA in 2008.

The early symposia were concerned with establishing the basics of how to estimate and characterize the behavior of an atomic frequency standard in an unambiguous and clearly identifiable way, and how to combine the reading of different clocks to form an optimal time scale within a laboratory. Later, as atomic frequency standards began to be used as components in larger systems, interest grew in understanding the impact of a clock in a more complex environment. For example, use of clocks in telecommunication networks in a Synchronous Digital Hierarchy created a need to measure the maximum time error spanned by a clock in a certain interval. Timekeeping metrologists became

interested in estimating time deviations and time stability, so they had to find ways to convert their common *frequency* characteristics to *time* characteristics. Tests of fundamental physics provided a motivation for launching atomic frequency standards into space in long-lasting missions, whose high-precision measurements might be available for only a few hours a day, yielding a series of clock data with many gaps and outliers for which a suitable statistical analysis was necessary to extract as much information as possible from the data. In the 21st century, the field has been transformed by the advent of atomic-clock-based Global Navigation Satellite Systems (GNSS), the steady increase in precision brought about by rapidly improving clocks and measurement systems, and the growing number of relatively inexpensive small clock ensembles.

Although technological transformations have raised the intensity and changed the details of the debates, the VITSAS conference showed that even the issues raised by the early symposia are still current. This selection of papers encompasses the full breadth of the VITSAS, including tutorials, laboratory-specific innovations and practices, GNSS applications, UTC generation, TWSTFT applications, GPS applications, small-ensemble applications, robust algorithms, and statistical measures that are either robust themselves or which reflect nonstationarity and robustness characteristics of the clocks.

The Editors of this special issue of *Metrologia* would like to express their thanks to the referees of the papers published here for all their hard work, to Drs Juan Palacio and Javier Galindo and the people of the ROA, and to all the attendees for the excellent symposium they have created.